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Building Collapse Due to Shallow Trench Excavation

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SYNOPSIS: A building collapse is investigated in which a shallow trench, excavated along the length of the building, resulted in the building's collapse. An investigation indicated that the trench had been excavated within 1 ft (0.3 m) of the foundation and that the foundation had been constructed on approximately 7 ft (2.1 m) of soft silty clay with the bottom portion of this soil highly saturated. The bearing capacity of the foundation, prior to excavation, was estimated to have a safety factor as low as 1.5. As a result of the proximity of the trench to the foundation and the soft soils, the trench collapsed soon after excavation. It is believed that the lower portion of the soil flowed into the trench causing a loss of bearing capacity. An understanding of the geologic setting of the foundation soils, coupled with soils information from the USDA's Soil Conservation Service, indicated the hazards of excavating in this soil.

INTRODUCTION

On July 16, 1989 a shallow trench was excavated along the length of a single-story building located in the City of Tuscaloosa, Alabama. The trench was being excavated for the installation of a sewer line to provide service to a rear portion of the building. The trench was approximately 3 ft (0.9 m) wide, starting from the southwest corner of the building and extending past the northwest corner of the building as shown in Figure 1. It was estimated that the trench was excavated to a depth of between 5 and 6 ft (1.5 to 1.8 m). A majority of the excavation was completed in a four hour period by a single backhoe operator. The collapse of the building occurred approximately one hour after the operator completed the excavation and was on a break. Fortunately, no injuries resulted when the building collapsed into the trench. A majority of the west wall of the building rotated into the trench resulting in the collapse of the building's roof.

Ensuing litigation resulted in the contractor in charge of the excavation being responsible for damages. Although the cause and effect relationship of the collapse appeared obvious, the extent and nature of the damage indicated that the foundation soils were in a relatively weak state prior to excavation. Consequently, a preliminary study was conducted to determine the factors that lead to the collapse of the building as well as ways of identifying such sites that may be susceptible to collapse from shallow trench construction, thus helping to prevent similar incidence.

SITE CONDITIONS

The City of Tuscaloosa is located in the west-central part of Alabama and has a population of approximately 75,000. The climate in Tuscaloosa is influenced by the Gulf of Mexico resulting in relatively warm humid summers accompanied by relatively mild winters. The average summer time temperature is 80°F, and the average winter time temperature is 46° F with an average annual precipitation of 52 in. The major physiographical feature of the area is the Black Warrior River Basin and the Black Warrior River. The Black Warrior River, which flows through Tuscaloosa, provides a major transportation link with the Gulf of Mexico and has two river lock systems within the corporate limits of Tuscaloosa. The city is located on the south bank of the Black Warrior River on a terrace approximately 50 to 75 ft (15 to 23 m) above the river's maintained level of 123 ft MSL (37.5 m). Beyond the banks of the Black Warrior River, Tuscaloosa tends from relatively flat terrain in the West to relatively steep hills to the East.

The collapsed building is located within a mixed residential/commercial section of Tuscaloosa in a southwest section of the city at the intersection of two streets as is shown in Figure 1. The building was used by an electrical contractor as both an office and warehouse at the time of the collapse. The area surrounding the building is characterized as a topographically low area but within a relatively flat section of Tuscaloosa.

The building was of cinder block construction with conventional strip footings, which were placed at grade level. The exterior walls of the building were load bearing walls as well as a center wall constructed along the length of the building. The east part of the building, which is

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still in use as a storage building, has a 10 ft (3.0 m) high flat roof, while the west one half of the building was used as a warehouse with a 16 ft (4.9 m) roof. The remaining concrete floor on the west side of the building is now used as an outdoor storage area. The footings were measured at 16 in. (406 mm) in width and 18 in. (0.5 m) in depth, while the combined bearing loads on the footings were estimated to be 325 psf (16 kPa). It is believed that the building was built in the late 1940s or early 1950s.

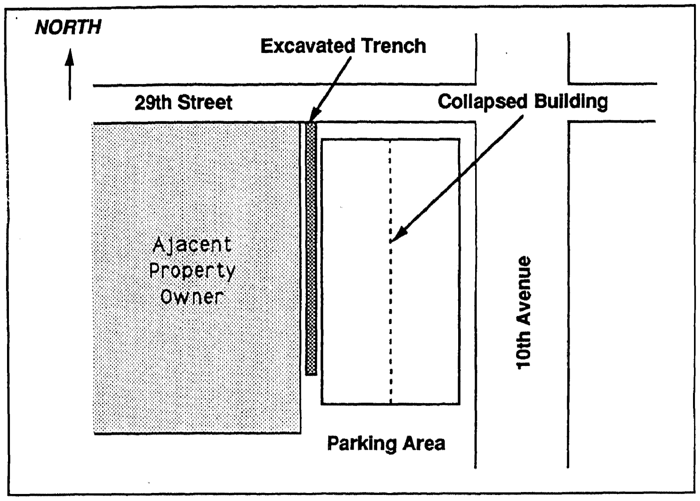

Figure 1 Plan view of the collapse building site.

GEOLOGIC CONDITIONS

Geologically, Tuscaloosa is located on the "fall line" that separates the Southern Appalachian Mountains (Appalachian Plateau Province) and the northern Gulf of Mexico coastal plains (Coastal Plain Province). The fall line is so named because it marks the area where river navigation from the Gulf of Mexico typically ends due to an increase in gradient of the rivers in Appalachian Mountain areas. In this region the Appalachian Plateau Province consists of relatively horizontal Paleozoic sedimentary rocks, while the Coastal Plain Province consists primarily of sedimentary Cretaceous materials overlain with younger Tertiary and Quaternary soils and rocks (Adams, et al., 1926).

The surface geology of the Tuscaloosa area consists of a very young unconsolidated sedimentary layer believed to be of Pleistocene age and described locally as "terrace deposits". These terrace deposits are alluvial deposits from the nearby Black Warrior River and in the Tuscaloosa area lie unconformally on the Pottsville Formation of Lower Pennsylvanian age (Wielchowsky, 1975). These deposits are believed to have been deposited during the melting of the great continental ice sheets during the final phases of the last ice sheet (Wisconsin) some 10 to 30 thousand years ago. The terrace deposits, which are 40 to 100 ft (12 to 30 m) thick in the Tuscaloosa area, are marked by coarse gravel at the bottom and become less gravelly and more sandy vertically until the upper layers are largely fine sand. The upper half is sandy in the lower part, yielding to red clayey soils near the top. The red clayey soils are characteristic of lateritic weathering (Adams, et al., 1926).

SOILS INVESTIGATION

Field Investigation

The field investigation consisted of a site investigation conducted within days of the collapse and a later investigation to obtain samples for soil testing. During soil sampling, however, it was found that obtaining undisturbed soil samples from the site was difficult. The first difficulty was in obtaining undisturbed samples in close proximity to the excavation. As is shown in Figure 2, the building was located within 6 ft (1.8 m) of an adjacent property and is bounded by streets and a parking lot in the rear of the building. The soils in the region of the collapse were all highly disturbed due to the collapse and could not be adequately sampled. Consequently, soil samples were taken from the rear of the building in the parking area. Six auger holes were placed through the surface of the parking lot. The second difficulty encountered was that at about 40 in. (1 m) of depth very soft saturated soils were encountered. While the soils were easily penetrated with a shelby tube, the saturated soil would not remain in the tube upon extraction. In fact, the auger hole itself did not stay open on account of the highly saturated soils. Undisturbed samples were, therefore, obtained only for the top 40 in. of the soil column. Auger holes were also placed in the area of the excavation to confirm the presence of the soft saturated soils. These auger holes also encountered very wet, saturated conditions with standing water at about 40 in. (1 m). However, since the trench had considerable debris placed in it after the collapse, this may have increased the permeability of the backfilled trench area allowing water to collect in this area.

Classification of the soils was based on the following tests: Atterberg limits, grain size analysis, natural water content, and unit weight tests. Strength measurements were obtained from uniaxial compression tests. The foundation soils were found to be a clayey silt CL-ML in the top 40 in. (1 m) tending to a low plasticity clay CL in a lower zone of 40 to 80 in. (1 to 2 m). The liquid limits of the soils, ranged from 16 to 40% while the plastic indexes were estimated to range from 1.5 to 18%. Void ratios for the undisturbed samples varied between 0.55 and 0.70. The natural water content ranged from 15% near the top of the soil column to 30% near the bottom of the column. The unconfined compressive strength of the soils in the upper 40 in. averaged 1060 psf (50 kPa). At a depth of about 80 in. (2 m), a very stiff clay, difficult to auger through, was encountered in all of the six auger holes completed. Figure 2 illustrates a cross-section of the building, its foundation soils and the estimated location of the excavation relative to the building.

Existing Soils Information

Since the foundations are relatively shallow and the strip footings located at a depth of 18 in. (457 mm), the USDA Soil Conservation Service soil survey of Tuscaloosa County (1981) was reviewed for additional information concerning the area's soils. This survey had been issued in August of 1981, with the major field work being conducted from 1971 to 1979. Figure 3 below shows the general soil map for the area of the building collapse. As can be seen from Figure 3, the building is located at the contact of a soil type

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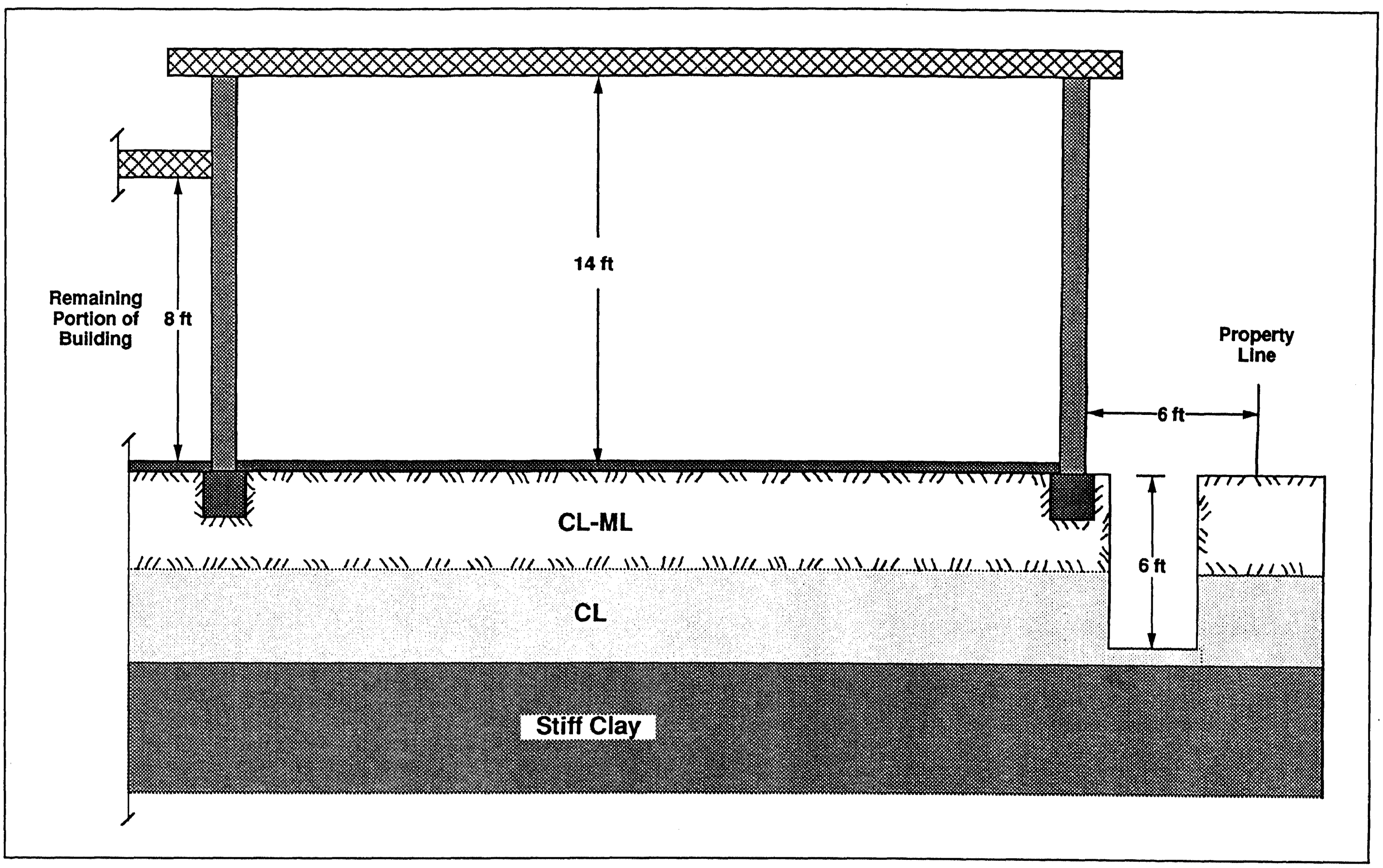

Figure 2 Cross-section of collapse building site.

identified as a number 2 and described in the soil survey as a Adaton silt loam. According to the soil survey, the Adaton series consists of deep, poorly drained, slowly permeable soils that formed in silty fluvial sediments. In addition, the soil survey provides information for planning land uses related to urban development such as building site development and engineering index properties. For building development, the Adaton soils were classified as being "severe" for building shallow excavations and dwellings without basements. This was primarily due to the soil's wetness and low strength. Figure 4 lists the engineering index properties of the Adaton soil series. It can be seen from Figure 4 that the basic engineering property tested confirmed the field test previously reported.

ANALYSIS

A site investigation immediately following the collapse found that the trench for the sewer line had been placed within 1 ft of the foundation. This was done due to the close proximity of the building to an adjacent property line, where only a 6 ft (1.8 m) strip of land was available for placement of the sewer line. Based on this finding, the excavation was in violation of applicable building codes, which require "that excavations for any purpose near structures should not extend within 1 ft (0.3 m) of the angle of repose or natural slope of the soil under any footing unless the structure is first properly underpinned or protected against settlement" (Southern Standard Building Code, 1961). Based on the soil strength measurements obtained, coupled with the information provided in the USDA soil survey of the area, it is highly unlikely that the building's foundation soils would be able to support a 5 to 6 ft excavation within 1 ft of the foundation. To address this issue, the geological setting of the foundation soils, a bearing capacity analysis prior to the excavation, the probable collapse mechanism, and compliance with existing building codes are discussed.

Geologic Considerations

A significant feature of the soils in the Tuscaloosa area is the alluvial origin of the unconsolidated terrace sediments deposited by the Black Warrior River. A well known characteristic of alluvial deposits is the extreme vertical and horizontal heterogeneity of the soils due to stream migration as well as flood water deposition. The USDA Soil Conservation Survey, presented in Figure 3, shows that the building was constructed at the edge of a pod-like section of Adaton silt. However, soil sampling revealed that a majority of the building, particularly the section that collapse, was constructed over approximately 7 ft (2.1 m) of Adaton silt. Other locations in the Tuscaloosa area in which the Adaton silt is found are primarily in stream

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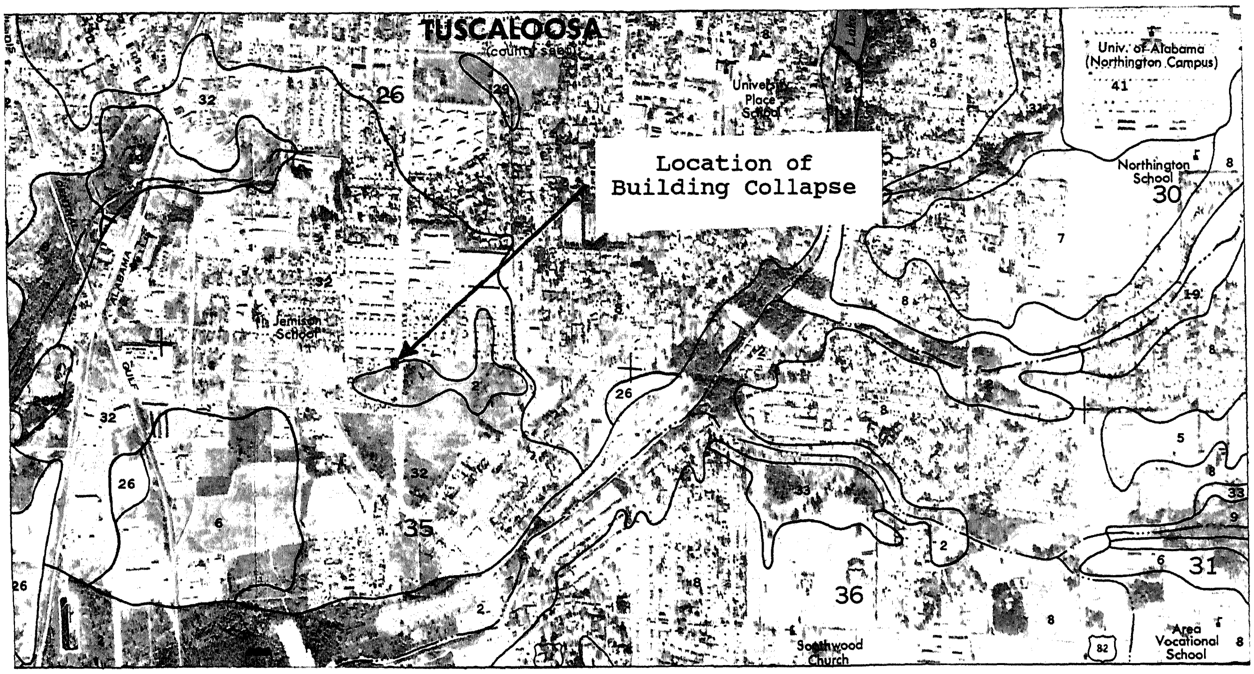

Figure 3 Soil Conservation Service soil survey.

Soil name and map symbol	Depth	USDA texture	Classification: Unified	Classification: AASHTO	Frag-ments > 3 inches	Percentage passing sieve number--: 4	10	40	200	Liquid limit	Plas-ticity index
	In				Pct					Pct	
2---------------- Adaton	0-7	Silt loam--------	ML, CL, CL-ML	A-4	0	100	98-100	90-100	84-100	<30	NP-10
	7-96	Silt loam, silty clay loam, silty clay.	CL, CH	A-6, A-7	0	100	98-100	95-100	84-100	30-52	11-30

Figure 4 Engineering index properties of the Adaton soil series (USDA, Soil Conservation Service).

channels. This can be seen in Figure 3 where Adaton silt is located to the southeast of the building collapse area.

The pod-like nature of this soil suggests that it was a low area where sediments collected over time. This low area may also have been part of an extended drainage system for receding flood waters but over time filled with sediment. As is typical of areas that accumulate sediment, the sediment tends to be silt, which is a highly erodible soil, along with some clays. The results of the Atterberg limits test indicate that the top portion of the foundation soils are a low plasticity silt that graded into a low plasticity clay. This would suggest that the foundation soils formed over a long period of time from surface erosion which would tend to collect more silty than clayey soils, as opposed to resulting directly from the receding flood waters. Since this area is topographically a low area, it would also tend to collect water. This was confirmed by field observations in which the auger holes encountered highly saturated soils in the lower portion of the auger holes. It appears that a stiff clay, located at a depth of about 7 ft (2 m), trapped water above it.

Bearing Capacity Analysis

Although only limited strength data was obtained from the site, an attempt was made to estimate the bearing capacity of the foundation prior to the excavation and subsequent building collapse. To perform a bearing capacity analysis, an estimate of the soil strength was made. Based on the unconfined compression test of the upper 40 in. (0.1 m), the soil had an average unconfined compressive strength of 1060 psf (50 kPa), giving an undrained shear strength of 530 psf (25 kPa) assuming $\phi=0$. However, the lower portion of the soil was not tested because undisturbed samples were not obtained. Based on field observation and moisture content measurements, which ranged from 25 to 30% for the soils in the 40 to 80 in. zone, it was assumed that the soil in this zone was relatively close to its liquid limit. According to Cassagrande (1932), soils near their liquid limit have an undrained shear strength of approximately 50 psf (2.4 kPa). This provides a conservative estimate of the undrained shear strength of the soil in the lower saturated soil. Using these estimates of shear strength for the

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foundation soils, a bearing capacity analysis was conducted assuming a strip footing supported by a two-layer soil. A recently proposed semiempirical equation by Azam and Wang (1991) for determining the ultimate bearing capacity of a two-layer c-ϕ soil was used in the analysis. The proposed bearing capacity equation is given as follows

$$q_o = q_t + (q_b - q_t)[1 - m(H_1/B)]^2$$

where

- q_o = ultimate bearing capacity of a strip footing over a two-layer soil;
- q_t = ultimate bearing capacity of the footing supported by an infinitely thick top-layer soil, computed by the traditional bearing-capacity equations using factors recommended by Vesic (1975);
- q_b = ultimate bearing capacity of the footing supported by an infinitely thick bottom-layer soil, computed by the same method as q_t;
- m = layer factor, which is 0.17-0.23 for two-layers of clay (use of the lower value is recommended if one clay layer is highly compressible);
- H_1 = distance between the base of the strip footing and the top of the bottom layer;
- B = width of the strip footing.

Azam and Wang analyzed four different layer combinations with one of the combinations a stiff clay underlain by a soft clay. While the overlying soil in this analysis cannot be classified as stiff, as compared to the properties of the soils tested by Azam and Wang, the analysis was used in hopes of providing a lower bound estimate of the bearing capacity of the foundation prior to the excavation. In addition, instead of computing the bearing capacity using factors recommended by Vesić (1975), a lower bound estimate of q_t and q_b was made assuming a simple uniaxial stress field below the footing which gives $q_{t\,or\,b}$ = 2c (Chen and McCarron, 1991). The resulting bearing capacities are as follows

$$q_t = 1060 \text{ psf } (51 \text{ kPa})$$
$$q_b = 100 \text{ psf } (5 \text{ kPa})$$

According to Azam and Wang's proposed equation, the ultimate bearing capacity of the strip footing over the two-layer soil is

$$q_t = 495 \text{ psf } (23 \text{ kPa})$$

Since the estimated bearing load on the footing was 325 psf (16 kPa), the foundation had a safety factor of approximately 1.5 against bearing capacity failure. According to Vesić (1975), however, situations in which safety factors are less than 2.0 should be avoided. Consequently, the foundation was below a minimum recommended safety factor prior to excavation of the trench. In addition, Vesić also recommends that "removal of existing overburden by scour or excavation should be given adequate consideration". It is unlikely that this was contemplated at the time of construction of the building or that an analysis was performed.

Collapse Mechanism

Based on the above analysis and information gathered at the site, the most probable collapse mechanism was that once the trench was excavated, the bottom soil, which was highly saturated and possibly near its liquid limit, flowed into the trench, thus undermining the upper bearing soils and resulting in the collapse of the building. This may also account for the time lag that occurred between the completion of the trench and the collapse, which was about 1 hour.

Azam and Wang also studied the plastic flow behavior of foundation soils using a finite element technique to gain insight into the progressive yielding of these soils. Their analysis of a stiff clay underlain by a weak clay revealed that the yield zone extends deep into the weaker bottom layer and that the yield pattern is typical of a punching shear of the top layer followed by a general shear failure of the bottom layer. Although the collapsed building's foundation soils were considerably weaker than those studied by Azam and Wang, it is possible that progressive yielding of the bottom soil also accounted not only for the collapse but also the time delay of the collapse.

Building Codes

According to the standard building code section on excavations, the excavation had been placed too close to the foundation since it was not at least 1 ft (0.3 m) from the angle of repose of the soil or from the natural slope of the soil. Since the "angle of repose" of a soil generally refers to a granular material in loosely packed state, the excavation angle would have to have been based on the natural angle of the soil. However, this is a difficult parameter to determine since the soils were a soft saturated silty clay. If it is assumed that the soils were at or close to their liquid limit, then the natural slope would be very low and would result in large distances required from the foundation for the excavation. Thus, the only possible solution for this excavation would have been to properly underpin or to prevent the bottom soils from flowing into the trench, both of which would have been difficult to complete given the limited space available as well as the cost involved.

An additional consideration in the collapse is that although the contractor was in violation of existing codes for excavation, their prior experience with other excavations in the Tuscaloosa area indicated that there should be no problem with the excavation, since they had excavated shallow trenches next to or near the foundation without resulting in a collapse of the trench. Therefore, no consideration was given to first testing the soils to determine if they were stable to excavate. In addition, the backhoe operator observed the lower soils in the trench slowly flowing into the trench but yet did not consider the situation as dangerous. While training of the operator was lacking in this case, information did exist from the USDA soil survey for this area that was readily obtainable and that would have indicated the possible dangers in excavating these soils. In addition, knowledge of the geologic origin of the soils in this area would also help alert operators to the occurrence of potentially difficult soils, since in this case, the alluvial nature of the soils should be relatively apparent given their location to the Black Warrior River.

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CONCLUSION

Conclusions concerning the building collapse can be summarized as follows:

1. The building had an estimated bearing capacity $SF \approx 1.5$ prior to collpase.
2. Bearing soils were found to be a low plasticity silty clay overlying a saturated low plasticity clay.
3. A trench was placed within 1 ft (0.3 m) of the foundation and in violation of applicable building codes for excavations.
4. Insufficient space was available between the foundation and an adjacent property to place the trench and meet existing codes for excavations.
5. Collapse of the building is believed to have resulted from the lower saturated clay flowing into the trench, thus undercutting the overlying soil and causing a loss of bearing capacity.
6. No investigation of soil conditions was made prior to the excavation nor were indications of imminent failure of the trench taken into consideration.
7. Information from the USDA Soil Conservation Service soil survey showed that the building probably was located on difficult soils which may cause problems with excavations, especially near foundations.
8. A significance of this collapse is that other structures in the Tuscaloosa area are also constructed on similar soils. Since information exists that can identify these types of soils, it can be used to help identify foundation soils that are potentially susceptible to collapse from adjacent shallow excavations.

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